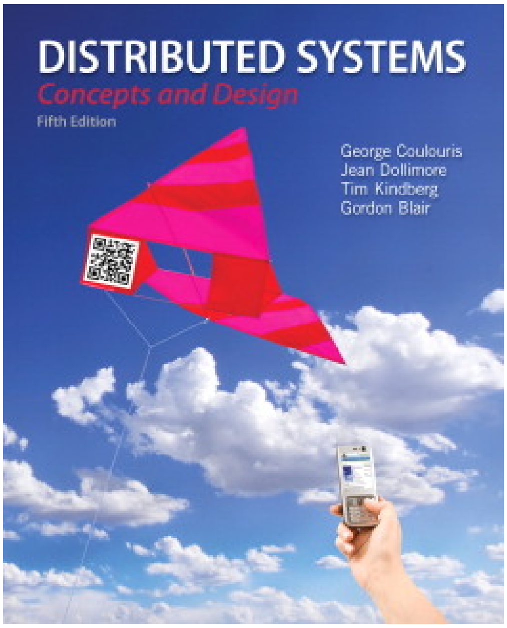
Distributed Systems
COMP90015 2017 SM2
Interprocess Communication

Interprocess Communication

From Coulouris, Dollimore and Kindberg, *Distributed Systems: Concepts and Design*, Edition 5, © Addison-Wesley 2012.



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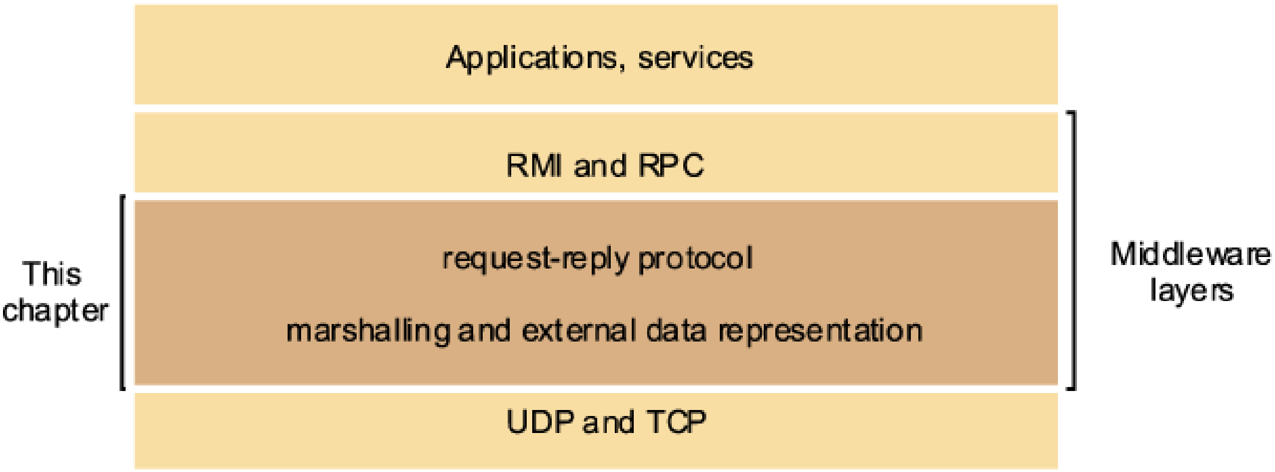
Overview

- Introduction
- The API for the Internet protocols
- External data representation and marshalling
- Group communication
- Overlay network

Introduction

This and the next chapters deal with middleware:

- This chapter deals with the lower layer of middleware that support basic interprocess communication
- The next one introduces high level communication paradigms (RMI and RPC)



UDP or User Datagram Protocol, does not guarantee delivery, while TCP or Transport Control Protocols provides a reliable connection oriented protocol.

- Java APIs for Internet protocols:
  - API for UDP:
    - Provides a *message passing* abstraction
    - Is the simplest form of Interprocess Communication (IPC)
    - Transmits a single message (called a *datagram*) to the receiving process
  - API for TCP:
    - Provides an abstraction for a two-way *stream*
    - Steams do not have message boundaries
    - Stream provide the basis for producer/consumer communication
    - Data sent by the producer are queued until the consumer is ready to receive them
    - The consumer must wait when no data is available

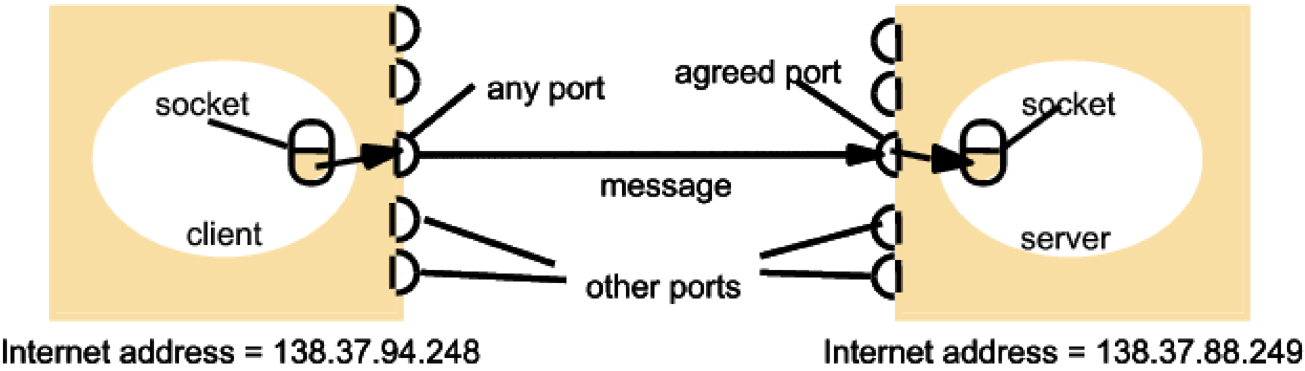
- Data Representation:
  - Deals with how objects and data used in application programs are translated into a form suitable for sending as messages over the network
- Higher level protocols:
  - Client-server communication: Request-reply protocols
  - Group Communication: Group multicast protocol

The API for the Internet protocols

- Processes use two message communication functions: send and receive
- A queue is associated with each message destination
- Communication may be *synchronous* or *asynchronous*
  - In synchronous communication, both *send* and the *receive* operations are *blocking* operations. When a send is issued the sending process is blocked until the receive is issued. Whenever the receive is issued the process blocks until a message arrives.
  - In asynchronous communication, the send operation is non-blocking. The sending process returns as soon as the message is copied to a local buffer and the transmission of the message proceeds in parallel. Receive operation can be blocking or non-blocking (non-blocking receives are not normally supported in today's systems).

Message Destinations

- Messages are sent to an **(Internet address, local port)** pair
- A port *usually* has exactly one receiver (except multicast protocols) but can have multiple senders
  - ♦ Recent changes allow multiple processes to listen to the same port, for performance reasons
- Location transparency is provided by a name server, binder or OS


socket
client
any port
agreed port
message
other ports
socket
server
Internet address = 138.37.94.248
Internet address = 138.37.88.249

Socket

A **Socket** provides an end point for communication between processes.

- Socket properties:
  - ♦ For a process to receive messages, its socket must be bound to a local port on one of the Internet addresses of the computer on which it runs.
  - ♦ Messages sent to a particular port of an Internet address can be only be received by a process that has a socket associated with the particular port number on that Internet address.
  - ♦ Same socket can be used both for sending and receiving messages.
  - ♦ Processes can use multiple ports to receive messages.
  - ♦ Ports cannot usually be shared between processes for receiving messages.
    - ◊ Recent changes allow multiple processes to listen on the same port.
  - ♦ Any number of processes can send messages to the same port.
  - ♦ Each socket is associated with a single protocol (UDP or TCP).

Java Internet Address

- Java provides a class which encapsulates the details regarding Internet Address -- `IntAddress`
- An instance of the `IntAddress` which contains the Internet address can be created by calling the static method `getByName`

```
IntAddress aComputer=IntAddress.getByName("sundowner.cis.unimelb.edu.au");
```

- The method throws UnknownHostException

UDP datagram communication

- Both the sender and the receiver bind to sockets:
  - ♦ Server (receiver) binds its socket to a server port, which is made known to the client
  - ♦ A client (sender) binds its socket to any free port on the client machine
  - ♦ The receive method returns the Internet address and the port of the sender, in addition to the message allowing replies to be sent
- Message Size:
  - ♦ Receiving process defines an array of bytes to receive the message
  - ♦ If the message is too big it gets truncated
  - ♦ Protocol allow packet lengths of 2^16 bytes but the practical limit is 8 kilo bytes.

- Blocking:
  - ♦ Non-blocking sends and blocking receives are used for datagram communication
  - ♦ Operation returns when the message is copied to the buffer
  - ♦ Message is delivered to the message buffer of the socket bound to the destination port
  - ♦ Outstanding or future invocations of the receive on the socket can collect the messages
  - ♦ Messages are discarded if no socket is bound to the port
- Timeouts:
  - ♦ Receive will wait indefinitely till messages are received
  - ♦ Timeouts can be set on sockets to exit from infinite waits and check the condition of the sender
- Receive generally allows receiving from any port. It can also allow to receive from only from a given Internet address and port.

- Possible failures:
  - ♦ Data Corruption: checksum can be used to detect data corruption
  - ♦ Omission failures: buffers full, corruption, dropping
  - ♦ Order: messages might be delivered out of order
- UDP does not suffer from overheads associated with guaranteed message delivery
  - ♦ Example uses of UDP:
    - ◊ Domain Name Service

* Voice Over IP (VOIP)

Java API for UDP datagram communication

- Java API provides two classes for datagram communication: `DatagramPacket`, `DatagramSocket`
- `DatagramPacket`
  - ♦ supports two constructors, one for creating an instance for sending and the other for creating an instance for receiving
  - ♦ other useful methods:
    - ◊ `getData()`
    - ◊ `getPort()`
    - ◊ `getAddress()`

Java API for UDP datagram communication

- `DatagramSocket`
  - supports two constructors, one takes port number and the other with no argument
  - useful methods: `send()`, `receive()`, `setSoTimeout()`, `connect()`

A Java UDP client

```
import  java.net.*;
import java.io.*;

public class UDPClient{
  public static void main(String args[]){
    // args give message contents and destination hostname
    DatagramSocket aSocket = null;
    try {
      aSocket = new DatagramSocket();
      byte [] m = args[0].getBytes();
      InetAddress aHost = InetAddress.getByName(args[1]);
      int serverPort = 6789;
      DatagramPacket request =
      new DatagramPacket(m,  args[0].length(), aHost, serverPort);
      System.out.println("Sending data to server");
      aSocket.send(request);
      byte[] buffer = new byte[1000];
      DatagramPacket reply = new DatagramPacket(buffer, buffer.length);
      System.out.println("Client waiting to receive a response");
      aSocket.receive(reply);
      System.out.println("Reply: " + new String(reply.getData()));
    }catch (SocketException e){System.out.println("Socket: " + e.getMessage());
    }catch (IOException e){System.out.println("IO: " + e.getMessage());
    }finally {if(aSocket != null) aSocket.close();}
  }
}
```

A Java UDP server

```
import java.net.*;
import java.io.*;

public class UDPServer{
  public static void main(String args[]){

  DatagramSocket aSocket = null;
    try{
    aSocket = new DatagramSocket(6789);
    // create socket at agreed port
    byte[] buffer = new byte[1000];
    while(true){
      DatagramPacket request = new DatagramPacket(buffer, buffer.length);
      System.out.println("Server waiting to receive data");
      aSocket.receive(request);
      System.out.println("Received Data: " + new  String(request.getData()));
      DatagramPacket reply = new DatagramPacket(request.getData(),
            request.getLength(), request.getAddress(), request.getPort());
      aSocket.send(reply);
    }
    }catch (SocketException e){System.out.println("Socket: " + e.getMessage());
    }catch (IOException e) {System.out.println("IO: " + e.getMessage());
    }finally {if(aSocket != null) aSocket.close();}
  }
}
```

TCP Stream Communication

- Features of stream abstraction:
  - ♦ **Message sizes**: There is no limit on data size applications can use.
  - ♦ **Lost messages**: TCP uses an acknowledgment scheme unlike UDP. If acknowledgments are not received the messages are retransmitted.
  - ♦ **Flow control**: TCP protocol attempts to match the speed of the process that reads the message and writes to the stream.
  - ♦ **Message duplication or ordering**: Message identifiers are associated with IP packets to enable the recipient to detect and reject duplicates and reorder messages in case messages arrive out of order.
  - ♦ **Message destinations**: The communicating processes establish a connection before communicating. The connection involves a connect request from the client to the server followed by an accept request from the server to the client.

- Steps involved in establishing a TCP stream socket:

  - ♦ **Client**:
    1. Create a socket specifying the server address and port
    2. Read and write data using the stream associated with the socket
  - ♦ **Server**:
    1. Create a listening socket bound to a server port
    2. Wait for clients to request a connection (Listening socket maintains a queue of incoming connection requests)
    3. Server accepts a connection and creates a new stream socket for the server to communicate with the client retaining the original listening socket at the server port for listening to incoming connections. A pair of sockets in client and server are connected by a pair of streams, one in each direction. A socket has an input stream and an output stream.

- When an application closes a socket, the data in the output buffer is sent to the other end with an indication that the stream is broken. No further communication is possible.
- TCP communication issues:
  - ♦ There should a pre-agreed format for the data sent over the socket
  - ♦ Blocking is possible at both ends
  - ♦ If the process supports threads, it is recommended that a thread is assigned to each connection so that other clients will not be blocked.

- Failure Model:
  - ♦ TCP streams use checksum to detect and reject corrupt packets and sequence numbers to detect and reject duplicates
  - ♦ Timeouts and retransmission is used to deal with lost packets

    - Under severe congestion TCP streams declare the connections to be broken hence does not provide reliable communication
    - When communication is broken the processes cannot distinguish between network failure and process crash
    - Communicating process cannot definitely say whether the messages sent recently were received
- Use of TCP: HTTP, FTP, Telnet, SMTP

Java API for TCP streams

- Following are the classes used for TCP stream communications:
    - `ServerSocket`:
        - Used to create a socket for listening
        - `accept()` method gets the connect request from the queue and returns an instance of Socket
        - `accept()` blocks until a connections arrives
    - `Socket`:
        - Is used by a pair of processes with a connection
        - Client uses a constructor specifying the DNS hostname and port of the server. This constructor creates the socket associated with a local port and connects it to the remote computer.
        - The methods, `getInputStream()` and `getOutputStream()` provide access to the two data streams.

A Java TCP client

```
import java.net.*;
import java.io.*;

public class TCPClient {
  public static void main (String args[]) {
  // arguments supply message and hostname
  Socket s = null;
  try{
    int serverPort = 7899;
    s = new Socket(args[1], serverPort);
    System.out.println("Connection Established");
    DataInputStream in = new DataInputStream( s.getInputStream());
    DataOutputStream out =new DataOutputStream( s.getOutputStream());
    System.out.println("Sending data");
    out.writeUTF(args[0]);      // UTF is a string encoding see Sn. 4.4
    String data = in.readUTF();   // read a line of data from the stream
    System.out.println("Received: "+ data) ;
  }catch (UnknownHostException e) {
     System.out.println("Socket:"+e.getMessage());
  }catch (EOFException e){
     System.out.println("EOF:"+e.getMessage());
  }catch (IOException e){
     System.out.println("readline:"+e.getMessage());
  }finally {
     if(s!=null) try {
       s.close();
     }catch (IOException e){
       System.out.println("close:"+e.getMessage());
     }
  }
  }
}
```

A Java TCP server

```
import java.net.*;
import java.io.*;

public class TCPServer {
  public static void main (String args[]) {
    try{
      int serverPort = 7899; // the server port
      ServerSocket listenSocket = new ServerSocket(serverPort);
      int i = 0;
      while(true) {
        System.out.println("Server listening for a connection");
        Socket clientSocket = listenSocket.accept();
        i++;
        System.out.println("Received connection " + i );
        Connection c = new Connection(clientSocket);
       }
     }
     catch(IOException e)
     {
       System.out.println("Listen socket:"+e.getMessage());
     }
  }
}
```

```
class Connection extends Thread {
  DataInputStream in;
  DataOutputStream out;
  Socket clientSocket;
  public Connection (Socket aClientSocket) {
    try {
      clientSocket = aClientSocket;
      in = new DataInputStream( clientSocket.getInputStream());
      out =new DataOutputStream( clientSocket.getOutputStream());
      this.start();
    } catch(IOException e) {
       System.out.println("Connection:"+e.getMessage());
    }
 }
 public void run(){
   try {           // an echo server
     System.out.println("server reading data");
     String data = in.readUTF();  // read a line of data from the stream
     System.out.println("server writing data");
     out.writeUTF(data);
  }catch (EOFException e){
     System.out.println("EOF:"+e.getMessage());
  } catch(IOException e) {
     System.out.println("readline:"+e.getMessage());
  } finally{
    try {
      clientSocket.close();
    }catch (IOException e){/*close failed*/}
  }
  }
}
```

External data representation and marshalling

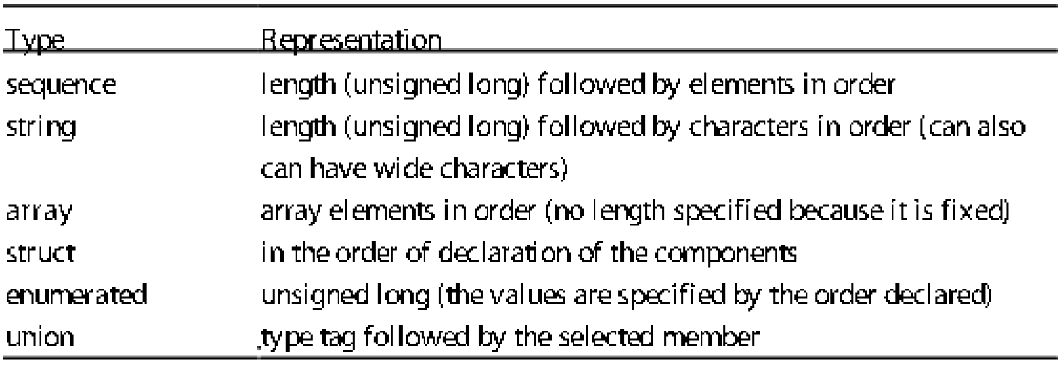
- Data structures in programs are flattened to a sequence of bytes before transmission
- Different computers have different data representations- e.g. number of bytes for an integer, floating point representation, ASCII vs Unicode. Two ways to enable computers to interpret data in different formats:
    - ♦ Data is converted to an agreed external format before transmission and converted to the local form on receipt
    - ♦ Values transmitted in the senders format, with an indication of the format used
- *External data representation*: Agreed standard for representing data structures and primitive data
- *Marshalling*: Process of converting the data to the form suitable for transmission
- *Unmarshalling*: Process of disassembling the data at the receiver

- Three approaches to external data representation:
    - ♦ CORBA's common data representation
    - ♦ Java's object serialization
    - ♦ Extensible markup language (XML)

Also, JSON is becoming popular, as a lightweight format for communication between servers and web browsers, but now also for general communication between components of a distributed system.

CORBA's Common Data Representation

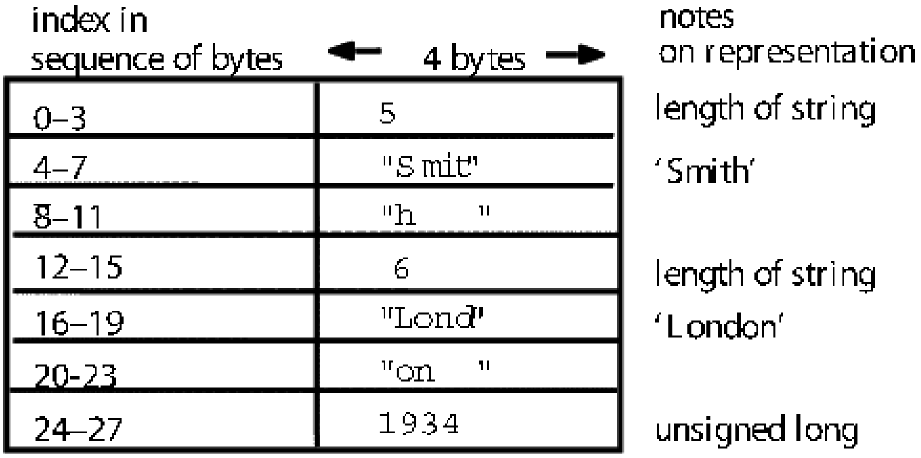
- CORBA CDR is the external data representation defined with CORBA 2.0
- Consists of 15 primitive data types including short, long, unsigned short, unsigned long, float, double, char, boolean, octet and any
- Primitive data types can be sent in big-endian or little-endian orderings. Values are sent in the sender's ordering which is specified in the message.
- Constructed Types -



Type	Representation
sequence	length (unsigned long) followed by elements in order
string	length (unsigned long) followed by characters in order (can also can have wide characters)
array	array elements in order (no length specified because it is fixed)
struct	in the order of declaration of the components
enumerated	unsigned long (the values are specified by the order declared)
union	type tag followed by the selected member

- Marshalling in CORBA - Marshalling operations can be automatically generated from the data type specification defined in the CORBA IDL (interface definition language). CORBA interface compiler generates the marshalling and unmarshalling operations.

CORBA CDR for a message that contains three fields of a `struct` whose types are `string`, `string` and `unsigned long`:



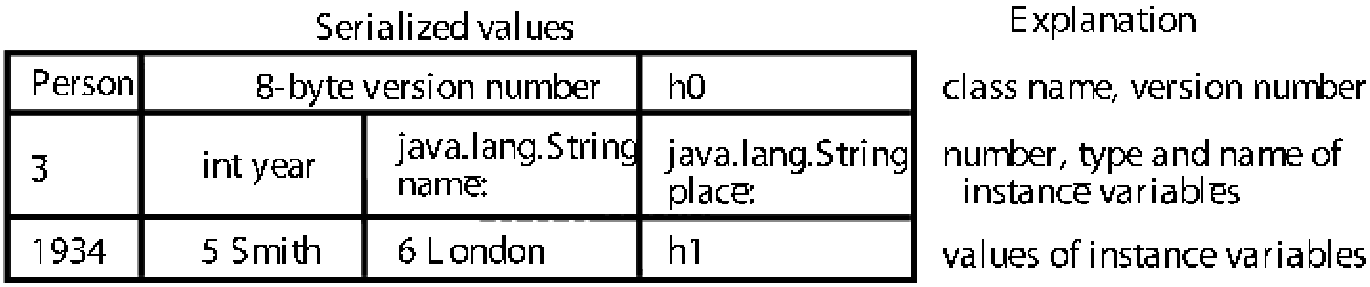
index in sequence of bytes	← 4 bytes →	notes on representation
0–3	5	length of string
4–7	"Smit"	'Smith'
8–11	"h "	
12–15	6	length of string
16–19	"Lond"	'London'
20-23	"on "	
24–27	1934	unsigned long

The flattened form represents a *Person* struct with value: {'Smith', 'London', 1934}

Java Object Serialization

- Serialization refers to the activity of flattening an object to be suitable for storage or transmission
- Deserialization refers to the activity of restoring the state of the object
- When a Java object is serialized:
  - ♦ Information about the class of the object is included in the serialization - e.g. name of class, version
  - ♦ All objects it references are serialized with it. References are serialized as handles (handle is a reference to an object within the serialized object)
  - ♦ Contents of primitive instance variables that are primitive types (integers, chars etc) are written in a portable format using methods in `ObjectOutputStream` class. Strings and characters are written using a method `writeUTF()` in the same class.

The object `Person p = new Person("Smith", "London", 1934)` in serialized form:



Serialized values				Explanation
Person	8-byte version number		h0	class name, version number
3	int year	java.lang.String name:	java.lang.String place:	number, type and name of instance variables
1934	5 Smith	6 London	h1	values of instance variables

The true serialized form contains additional type markers; h0 and h1 are handles

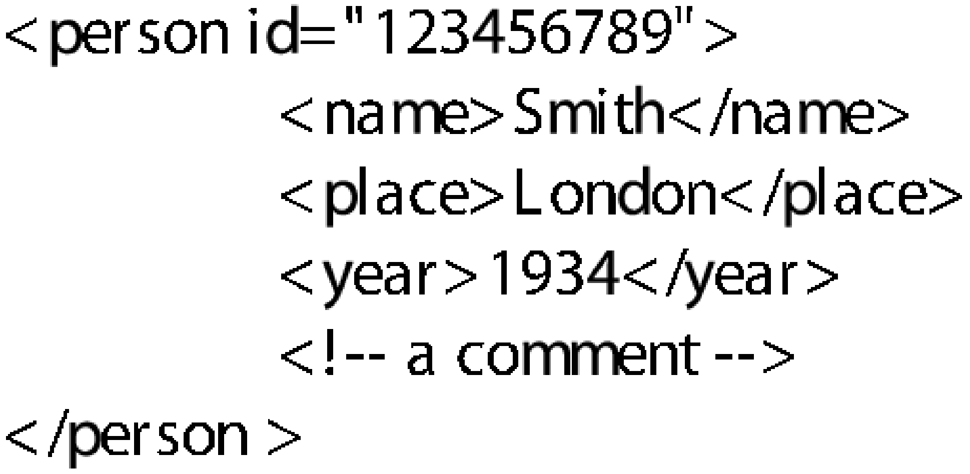
- During remote method invocation, the arguments and results are serialized and deserialized by middleware.
- *Reflection* property supported by Java allows serialization and deserialization to be carried out automatically.

Extensible markup language (XML)

- A *markup language* is a textual encoding representing data and the details of the structure (or appearance)
- XML is:
    - a markup language defined by World Wide Web Consortium (W3C)
    - tags describe the logical structure of the data
    - is extensible - additional tags can be defined
    - tags are generic - unlike HTML where tags give display instructions
    - self describing unlike CORBA CDR - tags describe the data
    - tags together with *namespaces* allow the tags to be meaningful
    - since data is textual, it can be read by humans and platform independent
    - since data is textual the messages are large causing longer processing and transmission times and more space to store

---

The XML definition of the `Person` structure:



```
<person id="123456789">
        <name>Smith</name>
        <place>London</place>
        <year>1934</year>
        <!-- a comment -->
</person >
```

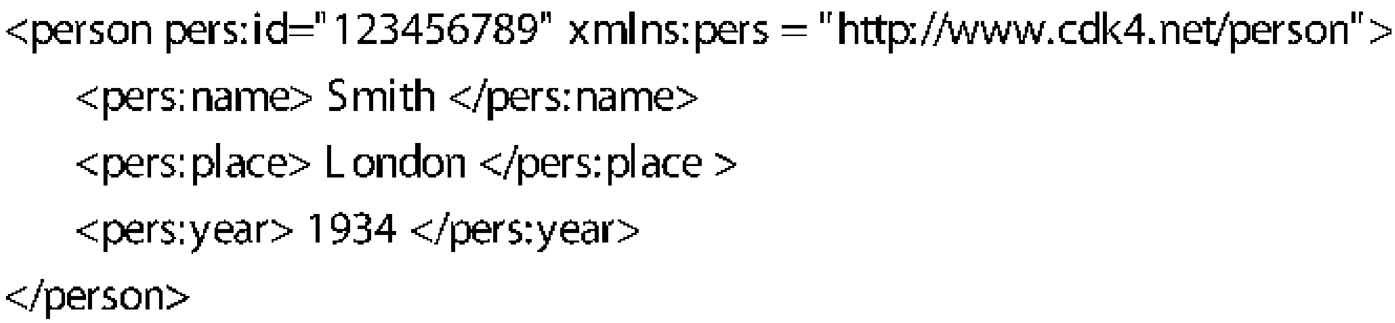
XML elements and attributes:

- *Element*
    - consists of data surrounded by tags - e.g. `<name>Smith</name>`
    - elements can be enclosed within elements - e.g. elements with the tag name is enclosed within the elements with tag person. This allows hierarchical representation.
    - an empty tag with no contents is terminated with `/>` - e.g. `<european/>` could be an empty tag included within `<person> </person>`
- *Attributes* - a start tag may optionally contain attributes (names and values) - e.g. `id="12345678"`

An attribute or an element can be used to represent data. If data contains substructures then an element has to be used. Attributes can only represent simple data types.

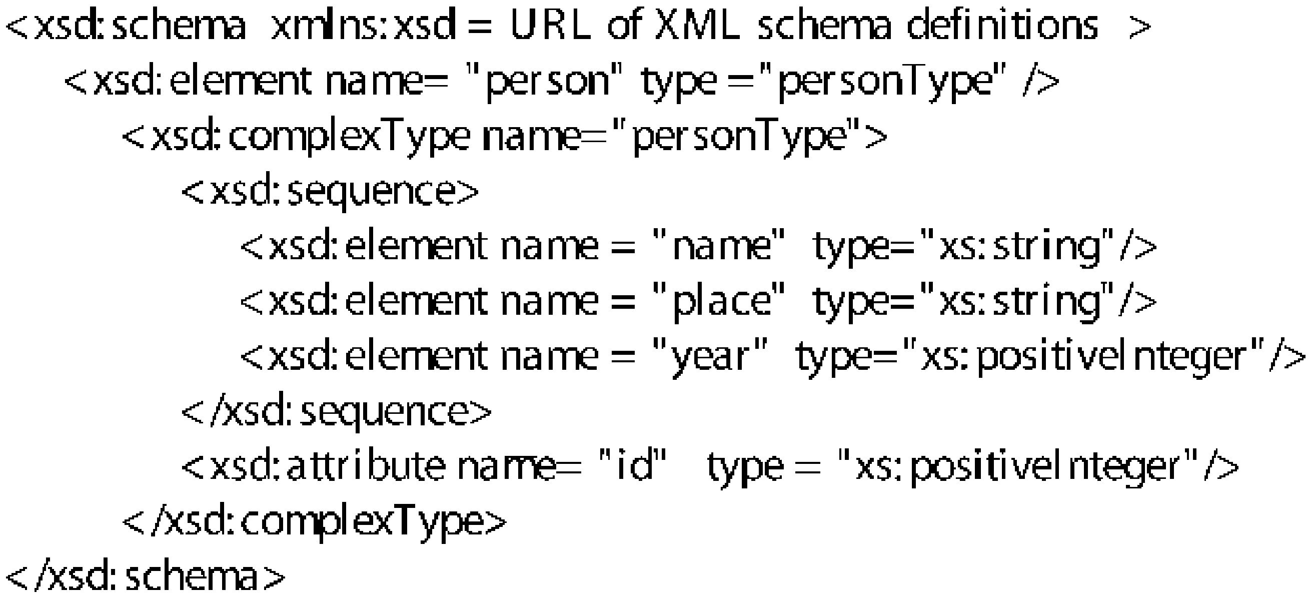
XML namespaces:

- is a name for a collection of element types and attributes, that is referenced by a URL
- namespace can be specified with an attribute `xmlns` whose value is the URL referring to the file containing the namespace definition - e.g `xmlns:pers = "http://www.cdk4.net/person"`



```
<person pers:id="123456789" xmlns:pers = "http://www.cdk4.net/person">
     <pers:name> Smith </pers:name>
     <pers:place> London </pers:place >
     <pers:year> 1934 </pers:year>
</person>
```

XML Schema defines the elements and attributes that can appear in a document.



```
<xsd:schema  xmlns:xsd = URL of XML schema definitions  >
    <xsd:element name= "person" type ="personType" />
        <xsd:complexType name="personType">
            <xsd:sequence>
                <xsd:element name = "name"  type="xs:string"/>
                <xsd:element name = "place"  type="xs:string"/>
                <xsd:element name = "year"  type="xs:positiveInteger"/>
            </xsd:sequence>
            <xsd:attribute name= "id"   type = "xs:positiveInteger"/>
        </xsd:complexType>
</xsd:schema>
```

JSON

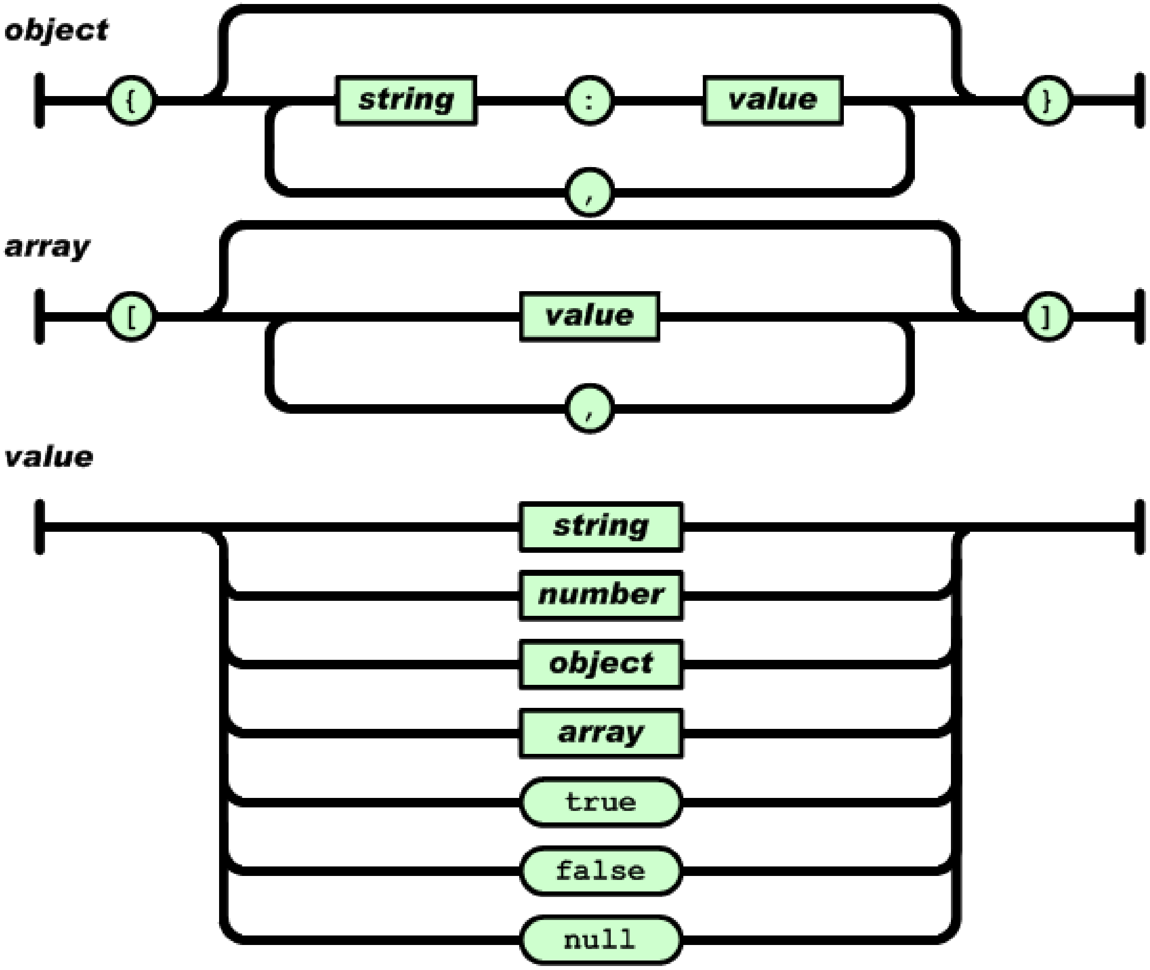
Javascript Object Notation is becoming the dominant format today.

```
{"employees":[
    {"firstName":"John", "lastName":"Doe"},
    {"firstName":"Anna", "lastName":"Smith"},
    {"firstName":"Peter", "lastName":"Jones"}
]}
```

versus

```
<employees>
    <employee>
        <firstName>John</firstName> <lastName>Doe</lastName>
    </employee>
    <employee>
        <firstName>Anna</firstName> <lastName>Smith</lastName>
    </employee>
    <employee>
        <firstName>Peter</firstName> <lastName>Jones</lastName>
    </employee>
 </employees>
```

From www.json.org



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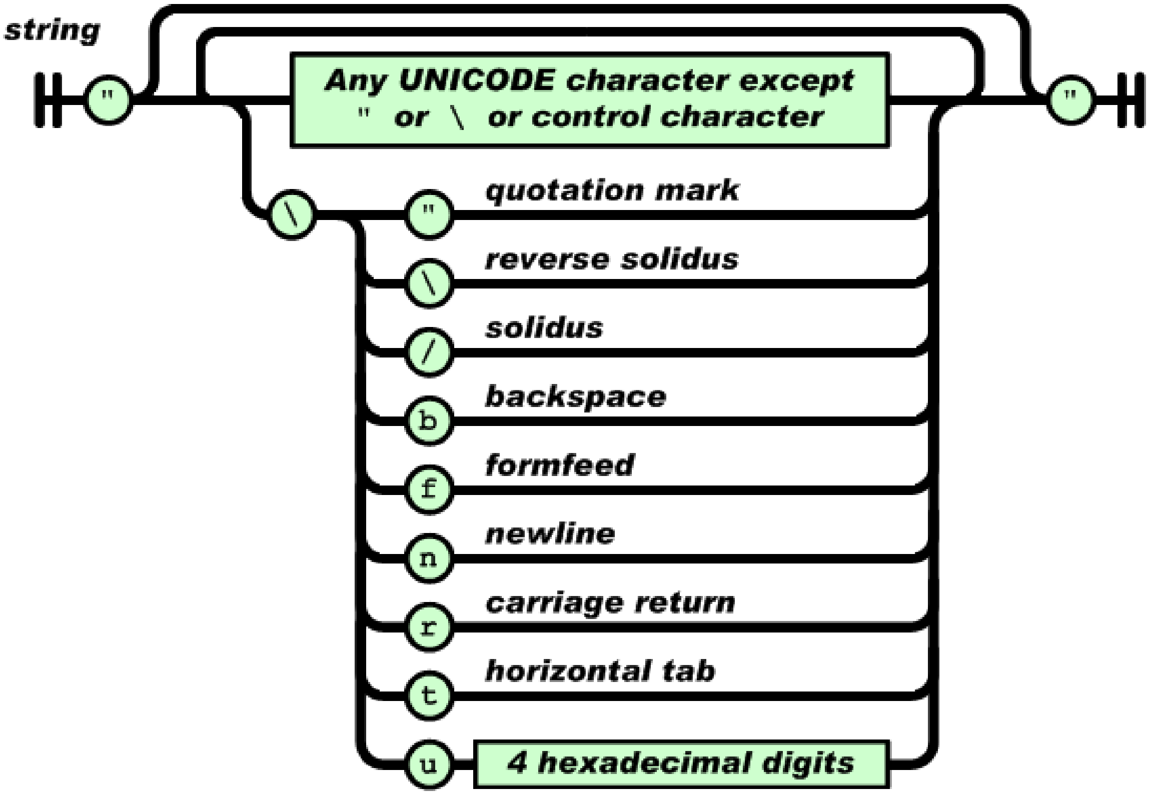
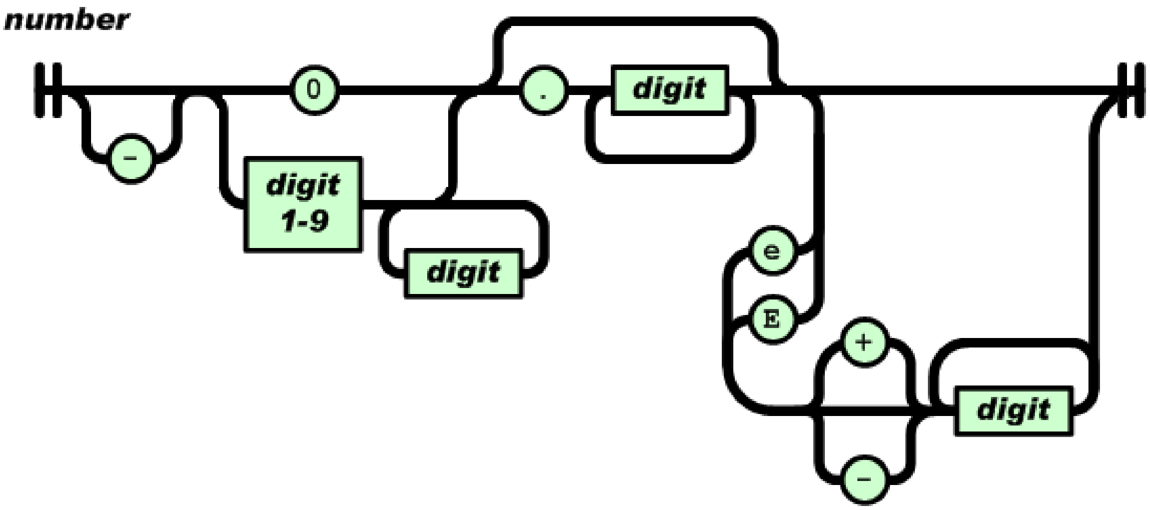


From www.json.org



Group communication

- A *multicast operation* allows group communication - sending a single message to number of processes identified as a group
- Multicast can happen with or without guarantees of delivery
- Uses of multi cast:
    - ♦ Fault tolerance based on replicated services
    - ♦ Finding discovery servers
    - ♦ Better performance through replicated data

  - propagation of event notification

IP multicast - example

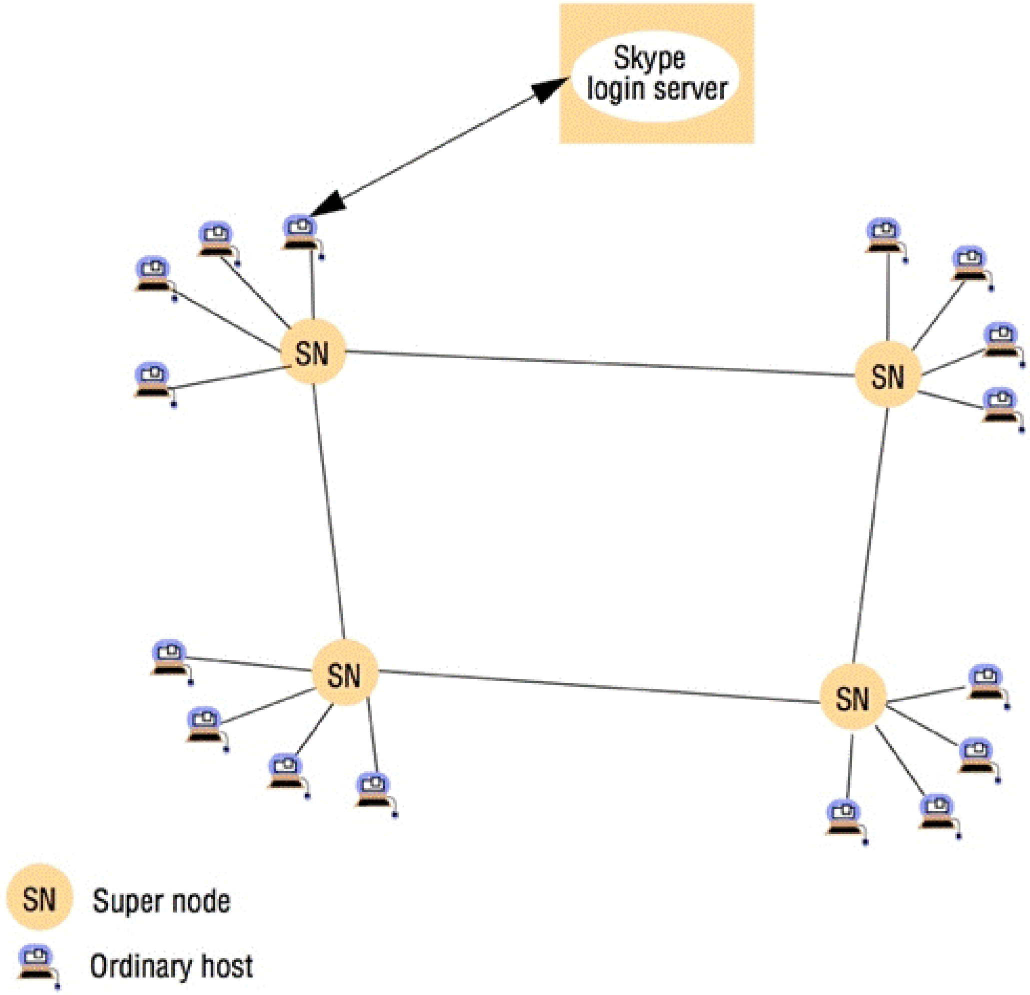
- Allows a sender to transmit a single packet to a set of computers that form the group
- The sender is not aware of the individual recipients
- The group is identified by a class D Internet address (address whose first 4 bits are 1110 in IPv4)
- IP multicast API:
  - available only for UDP
  - an application can send UDP datagrams to a multicast address and ordinary port numbers
  - an application can join a multicast group by making its socket join the group
  - when a multicast message reaches a computer, copies are forwarded to all processes that have sockets bound to the multicast address and the specified port number
- Failure model: Omission failures are possible. Messages may not get to one or more members due to a single omission

A Java multicast peer

```
import java.net.*;
import java.io.*;
public class MulticastPeer{
  public static void main(String args[]){
    // args give message contents and destination multicast group (e.g. "228.5.6.7")
    MulticastSocket s =null;
    try {
      InetAddress group = InetAddress.getByName(args[1]);
      s = new MulticastSocket(6789);
      s.joinGroup(group);
      byte [] m = args[0].getBytes();
      DatagramPacket messageOut = new DatagramPacket(m, m.length, group, 6789);
      s.send(messageOut);
      byte[] buffer = new byte[1000];
      for(int i=0; i< 3;i++) {// get messages from others in group
        DatagramPacket messageIn = new DatagramPacket(buffer, buffer.length);
        s.receive(messageIn);
        System.out.println("Received:" + new String(messageIn.getData()));
      }
      s.leaveGroup(group);
   }catch (SocketException e){
      System.out.println("Socket: " + e.getMessage());
   }catch (IOException e){
      System.out.println("IO: " + e.getMessage());
   }finally {if(s != null) s.close();}
 }
}
```

Overlay networks

The distributed system forms its own communication network over the Internet, e.g. Skype.



Skype
login server
SN
SN
SN
SN
SN Super node
Ordinary host